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(54) **Catadioptric optical system and exposure apparatus having the same**

(57) The projection exposure lens with an object side catadioptric system (CS), an intermediate image (IMI) and a refractive lens system (RL) is made with lenses of a first material and with lenses of a second material, whereby no more than four, preferable no more then three lenses are made of said second material. The catadioptric system (CS) has at least one positive lens (201/202) between the object side (O) and a first deflecting element (DM1) and not more than one positive lens (203/204) and not more than three negative lenses (205/206, 207/208) between the first deflecting element (DM1) and a concave mirror (209). The refractive lens system (RL) is composed of a field lens group (FLG), an intermediate correcting lens group (220 —231) and a focussing lens group (FOG).

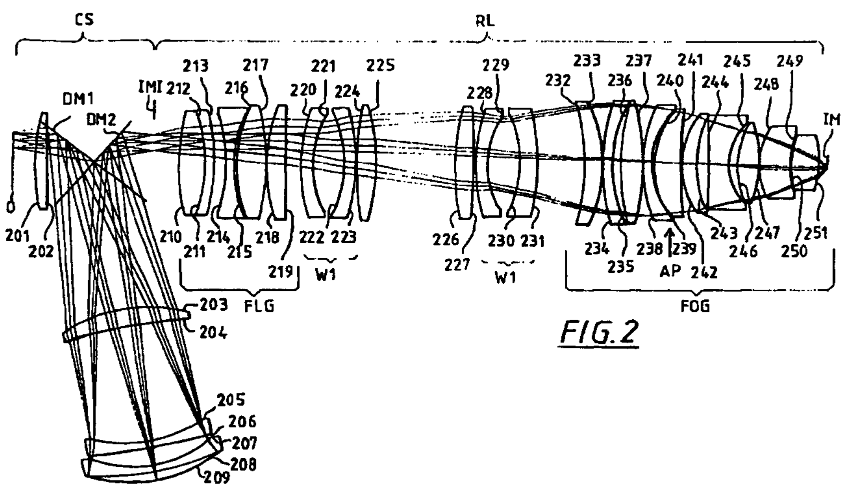

FIG. 2

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Description

Background of the Invention

1. Field of the Inventi n

[0001] The present invention relates to a projection exposure lens in a projection exposure apparatus such as a wafer scanner or a wafer stepper used to manufacture semiconductor elements or other microstructure devices by photolithography and, more particularly, to a catadioptric projection optical lens with an object side catadioptric system, an intermediate image and a refractive lens system for use in such a projection exposure apparatus.

2. Related Background Art

[0002] US 4,779,966 to Friedman gives an early example of such a lens, however the catadioptric system being arranged on the image side. Its development starting from the principle of a Schupmann achromat is described. It is an issue of this patent to avoid a second lens material, consequently all lenses are of fused silica. Light source is not specified, band width is limited to 1 nm.

[0003] US 5,052,763 to Singh (EP 0 475 020) is another example. Here it is relevant that odd aberrations are substantially corrected separately by each subsystem, wherefore it is preferred that the catadioptric system is a 1:1 system and no lens is arranged between the object and the first deflecting mirror. A shell is placed between the first deflecting mirror and the concave mirror in a position more near to the deflecting mirror. All examples provide only fused silica lenses. NA is extended to 0,7 and a 248 nm excimer laser or others are proposed. Line narrowing of the laser is proposed as sufficient to avoid chromatic correction by use of different lens materials.

[0004] US 5,691,802 to Takahashi is another example, where a first optical element group having positive retracting power between the first deflecting mirror and the concave mirror is requested. This is to reduce the diameter of the mirror, and therefore this positive lens is located near the first deflecting mirror. All examples show a great number of CaF_2 lenses.

[0005] EP 0 736 789 A to Takahashi is an example, where it is requested that between the first deflecting mirror and the concave mirror three lens groups are arranged, with plus minus plus refractive power, also with the aim of reducing the diameter of the concave mirror. Therefore, the first positive lens is located rather near to the first reflecting mirror. Also many CaF_2 lenses are used for achromatization.

[0006] DE 197 26 058 A to Omura describes a system where the catadioptric system has a reduction ratio of $0,75 < /\beta_1/ < 0,95$ and a certain relation for the geometry of this system is fulfilled as well. Also many CaF_2 lenses are used for achromatization.

[0007] For purely refractive lenses of microlithography projection exposure system a lens design where the light beam is twice widended strongly is well known, see e.g. Glatzel, E., Zeiss-Information 26 (1981), No. 92 pages 8-13. A recent example of such a projection lens with + - + - + lens groups is given in EP 0 770 895 to Matsuzawa and Suenaga.

[0008] The refractive partial objectives of the known catadioptric lenses of the generic type of the invention, however show much simpler constructions.

[0009] The contents of these documents are incorporated herein by reference. They give background and circumstances of the system according to the invention.

3. Summary of the Invention

[0010] It is an object of the present invention to obtain a catadioptric optical system of new construction principles allowing for large numerical aperture, large image field, sufficient laser bandwidth, solid and stable construction, which takes into account the present limitations on availability of CaF_2 in quantity and quality. This holds for a DUV projection lens and gives the basis for a one material only lens for VUV (157 nm).

[0011] In order to achieve the above object, according to the present invention, there is provided a projection exposure lens according to one of claims 1 to 7 or any combination of them as claimed in claim 8.

[0012] Advantageous versions are obtained when including features of one or more of the dependent claims 8 to 28.

[0013] An advantageous projection exposure apparatus of claim 29 is obtained by incorporating a projection exposure lens according to at least one of claims 1 to 28 into a known apparatus.

[0014] A method of producing microstructured devices by lithography (claim 30) according to the invention is characterized by the use of a projection exposure apparatus according to the preceeding claim 29. Claim 31 gives an advantageous mode of this method.

[0015] The present invention will be more fully understood from the detailed description given hereinbelow and the accompanying drawings, which are given by way of illustration only and are not to be considered as limiting the present

invention. Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art from this detailed description.

4. Brief description of the drawings

[0016]

Figure 1 is a view showing the arrangement of an exposure apparatus to which a catadioptric optical system according to the present invention can be applied;

Figure 2 is a section view of the lens arrangement of a first embodiment;

Figure 3 is a section view of the lens arrangement of a second embodiment;

Figure 4 is a section view of the lens arrangement of a third embodiment;

Figure 5 is a section view of the lens arrangement of a fourth embodiment;

Figure 6a is a section view of the lens arrangement of a fifth embodiment;

Figure 6b is a representation of an imaging error of the fifth embodiment; and

Figure 7 is a schematic section view of part of the lens arrangement of a sixth embodiment.

[0017] The projection exposure apparatus as schematically shown in Figure 1 includes an excimer laser light source 1 with an arrangement 11 moderately narrowing bandwidth. An illumination system 2 produces a large field, sharply limited and illuminated very homogeneously, which matches the telecentricity requirements of the projection lens, and with an illumination mode to choice. Such mode may be conventional illumination of variable degree of coherence, annular or quadrupole illumination.

[0018] A mask 3 is displaced in the illuminated area by a mask holding and handling system 31, which includes the scanning drive in case of a wafer scanner projection exposure apparatus. Subsequently follows the catadioptric projection exposure lens 4, according to the invention to be described in detail subsequently.

[0019] This lens 4 produces a reduced scale image of the mask 3 on a wafer 5. The wafer 5 is held, handled and eventually scanned by unit 51.

[0020] All systems are controlled by control unit 6. Such unit and the method of its use is known in the art of microlithographic projection exposure.

[0021] However, for exposure of structures in the regime of about 0,2 μm and less resolution at high throughput there is a demand for various projection exposure lenses capable to be operated at 193 nm, eventually also at 248 nm or 157 nm excimer laser wavelengths with reasonably available bandwidths (e.g. 15 pm at 193nm), at high image side numerical aperture of 0,65 to 0,8 or more and with reasonably large rectangular or circular scanning image fields of e.g. 7 x 20 to 10 x 30 mm^2.

[0022] Catadioptric systems of the type cited above are in principle suitable for this.

[0023] However, according to the invention a number of measures and features has been found to improve these systems.

[0024] The example shown in the sectional view of Figure 2 has the lens data given in Table 1 and makes use only of fused silica lenses. As only one lens material is used, this design can easily be adapted for other wavelengths as 248 nm or 157 nm.

[0025] The intermediate image IMI is freely accessible, so that it is easily possible to insert a field stops. The aperture stop AP is located between lens surfaces 139 and 140 and is also well accessible.

[0026] The deflecting mirrors DM1 and DM2 in the catadioptric system CS are defined in their geometry by the demands of separation of the light beams to and from the concave mirror 109 and of clearance from lens 201, 202. It is advantageous, that the mirror angle of mirror DM1 differs from 45°, such that the beam deflection angle is greater than 90°. This helps to ascertain large free working distance as well as wide clearance for the light beam relative to the first lens element 201, 202 and also gives full clearance of the lens barrel of the catadioptric systems CS from the object plane 0.

[0027] The arrangement of the two deflection mirrors DM1, DM2 allows for a straight optical axis and parallel situation

of origin plane 0 and image plane IM, i.e. mask and wafer are parallel and can easily be scanned. However, one of the deflecting mirrors DM1, DM2 can be abandoned or eventually be replaced by a deflecting mirror in the refractive lens RL, e.g. in the air space between lens surfaces 225 and 226. It is also clear that the deflecting mirrors can be replaced by other deflecting optical elements (as e. g. the prism in embodiment 6 or others).

[0028] A moderate positive lens 201, 202 is placed near the origin plane 0 in the single pass beam area. Its focal length is approximately equal to its distance from the concave mirror 209. This makes that the concave mirror 209 is situated in a pupil plane and thus the diameter required is minimized.

[0029] A second positive lens is located in the doubly passed area between the deflecting mirrors DM1, DM2 and the concave mirror 209. As the production conditions of concave mirrors of 200 mm to 300 mm diameter give no strong preference to smaller units - in contrast to lenses, namely such made from CaF_2, where inhomogeneties etc. give strong limitations - there is no need to use this positive lens 203, 204 for reduction of the radius of the concave mirror 209. It is located nearer to the concave mirror 209 than to the first reflection mirror DM1 at a location where it serves best to minimize imaging errors.

[0030] The two negative menisci 205, 206; 207, 208 cooperate with the concave mirror 209 in a known manner, giving increased angles of incidence and stronger curvature, thus stronger correcting influence of the concave mirror 109.

[0031] It is significant, that the number of lenses in the doubly passed area of the catadioptric system CS is restricted to three, as here every lens counts doubly with respect to system energy transmission and wavefront quality degradation - without giving more degrees of freedom for correction.

[0032] Of a total reduction ratio of $\beta = 0,25$ the catadioptric system CS delivers its part of $\beta_{CS} = 1,008$.

[0033] At the intermediate image plane IMI preferably a field stop FS is inserted, which reduces stray light favourably.

[0034] The refractive lens RL following to the intermediate image IMI is of more elaborate design than usual in the art. It is more of a quality as fully refractive projection exposure lenses of recent developments tend to be.

[0035] One can see that the five lens group design known from sophisticated refractive microlithography lens designs featuring two waists and three bellies with + - + - + lens groups in this sequence is adopted. Though the first two bellies (lens surfaces 210 to 219, 224 to 227) are not very strongly expressed, the two waists W1, W2 are significantly established, each by a pair of negative menisci 220, 221; 222, 223 and 228, 229; 230, 231, whose convex surfaces face outwardly.

[0036] It is known that these lens groups at the waists W1, W2 as the others can be developed further by incorporating more lenses, e.g. to increase the numerical aperture or the image area.

[0037] From another point of view, the refractive lens RL is composed of a field lens group FLG (lens surfaces 210 to 219) of positive power for turning the diverging chief ray into a converging chief ray, an image side positive focussing lens group FOG (lens surfaces 232 to 251 which generates the required large numerical aperture, and intermediately arranged lens elements, which correct imaging errors, especially including sets of oppositely arranged negative menisci (w1, w2).

[0038] The -+ power doublets with surfaces 235 to 238 and 239 to 242 are the key to the wide spectral bandwidth at good correction of the chromatic variation in spherical aberration, which is the main residual aberration in these designs. It was found that the alternative arrangement there of +- power doublets give much worse chromatic variation of spherical aberration. Here a value of 0,35 µm is obtained at 15 pm laser bandwidth.

[0039] This example of figure 2 is suitable for printing microstructures at a resolution of less than 0,2 µm over an image field of 30 x 7 mm^2 rectangle at 6 mm off axis, with an excimer laser source of 0,015 nm bandwidth.

[0040] Figure 3 and Table 2 show a design variant. The catadoptric system CS remains very similar, however its reduction ratio now is less than unity at $\beta_{CS} = 0,944$.

[0041] In the refractive lens the second lens 212, 213 of Figure 2 is abandoned, while the thick negative lens 245, 246 is split into three units 342, 343; 344, 345; 346, 347.

[0042] Also two lenses now are made of CaF_2, namely the elements with the surfaces 342, 343 and 348, 349. Related to the diameter of the greatest lens 332, 331 of ca. 250 mm their diameters of ca. 205 mm and approx. 165 mm are less than 0,81 fold and 0,67 fold. Therefore, their dimension is not too great and effective production is ascertained.

[0043] Also they both are arranged in the converging light beam in the fifth lens group after the third belly, near the image plane. They help with achromatization. The other features are quite similar as those of the example of Figure 2, including e.g. the -+ power doublets 332 to 339.

[0044] Fig. 4 and table 3 show another example of a catadioptric lens according to the invention.

[0045] Now, the catadioptric system CS shows a major revision, as all lenses in the doubly passed region are combined into a single lens group next to the concave mirror 411. It includes the positive lens 403, 404 and three negative lenses 405 to 410. Change from two to three such negative lenes provides smoother increase of beam angles and thus optimizes correction. Thus, the construction of the lens barrel of the catadioptric system CS is simplified. The lenses 403 to 410 and the mirror 411 can be mounted in a compact unit of conventional construction as known from refractive projection exposure lenses. The long distance to the deflecting mirrors DP1, DP2 can be bridged by a thermally stable tubular body, e.g. made of fiber compound, glass ceramics or a bi-metal compound structure.

[0046] The positive lens 403, 404 now is made of fluorite (ca. 200 mm dia.), thus helping in achromatization. It is significant for the invention, that at most three to four lenses in total made of a second material are sufficient to provide good achromatization in this basic design.

[0047] The reduction ratio of the catadioptric system is β_{CS} = 0,931. The refractive lens system is constructed very similar to the one of table 2.

[0048] A fourth embodiment is given in Fig. 5 and table 4.

[0049] Now the catadioptric system CS again is free of any CaF_2 element. Its principal construction with a compact unit of one positive (503, 504), three negative lenses (505-510) and the concave mirror 511 in one compact unit remains the same as in the third embodiment. The reduction ratio β_{CS} is 0,961 in the most preferred range.

[0050] Also the refractive lens RL is of the same overall design as the before mentioned examples. However, the use of CaF_2 lens elements has a novel character: While lens element 544, 545 in a known manner serves for achromatization, the reason for use of CaF_2 in the two lenses 552, 553; 554, 555 next to the image plane IM is another one:

[0051] The reason for use of CaF_2 here is the reduction of the "compaction" degradation effect which is rather strong with fused silica lenses at high light intensity and strong asymmetry (caused by narrow scanning image field) at 193 nm wavelength, but far less with CaF_2 lenses (or other crystalline material).

[0052] With an overall length - object 0 to image IM - of 1455 mm, a deviation off the axis of the concave mirror 511 of 590 mm, diameter of the concave mirror 511 of 250 mm, greatest lens diameter in the refractive lens system RL of 240 mm (at lens 534, 535) and diameters of the CaF_2 lenses of 195 mm (544, 545), 135 mm (552, 553) and 85 mm (554, 555) the dimensions of this construction are very acceptable. At Lambda = 193 nm, 15 pm band width, reduction ratio 0,25, numerical aperture of 0,7, an image field of 26 x 9 mm^2 rectangular is imaged at a resolution of better than 0,20 µm.

[0053] A fifth embodiment is given in Fig. 6a and table 5. This is distinguished from embodiment 4 in that only the last two lenses C1, C2 (654, 655; 656, 657 are made of CaF_2 with the aim of reduction of long-time degradation by compaction of fused silica under 193 nm radiation, but no CaF_2 is used for the purpose of achromatization.

[0054] The catadioptric system CS consists of a field lens 601, 602 with a focal length f' related to its distance B to the concave mirror by f'/B = 1.004.

[0055] Deflecting mirror DM1 deflects the optical axis. Its normal is tilted with respect to the optical axis by 50°. This gives better beam clearance from the field lens 601, 602 than the normal 45°.

[0056] The positive lens 603, 604 is combined with three negative lenses 605-610 and the concave mirror 611 into a compact unit. The distance DM1-603 is 432 mm, compared to the distance DM1-611 to the concave mirror of 597 mm this is 72 %.

[0057] The reduction ratio of the catadioptric system β_{CS} = 0,9608 lies in a preferable range near unity, where the achromatizing effect of the concave mirror is best exploited as well as other imaging errors (e.g. curvature of field) are kept small. The positive effect on Petzval sum is very good.

[0058] However, the concept of odd aberrations correction (Singh loc. cit.) is not adapted: At the intermediate image plane IMI the values of coma - 0,1724 - and distortion - -0,0833 - by far exceed good correction values, while at the final image plane IM coma (-0,00098) and distortion (-0,000115) are very well corrected, as other typical errors are.

[0059] A field stop FS at the intermediate image plane IMI advantageously cuts off disturbing stray light.

[0060] According to the invention the catadioptric system is designed with very few elements in compact arrangement and its function is focussed on the implementation of the achromatizing and Petzval sum influence of the concave mirror 611.

[0061] Detailed correction is the realm of the refractive lens system RL. This is composed of a field lens group FL (surfaces 612 to 621) and a focussing lens group FG (surfaces 634 to 655). Correcting lens elements are inserted in between, including two pairs of opposing negative menisci 622-625 and 630-633. These form two beam waists W1, W2. Thus, the +-+-+ five lens group design known from sophisticated refractive projection exposure lenses is established.

[0062] The focussing lens group FG hosts the system aperture AP as well as two -+power lens groups PG1 and PG2 with the above mentioned advantages.

[0063] No achromatizing CaF_2 lens is provided, but as in embodiment 4 the two lenses C1, C2 (652-655) located next the image plane IM are made of CaF_2 for the above mentioned reason of avoidance of compaction.

[0064] At a length 0-IM of 1400 mm and a sideward deviation of 590 mm to the concave mirror 611, the diameter of the concave mirror 611 (and the neighboring lens 609, 610) is limited to 252 mm, while the largest lens 636, 637 of the refractive lens system RL has a diameter of 240 mm and the CaF_2 lenses have only 130 mm (C1) and 85 mm (C2) diameter. Thus requirements of production to avoid extreme diameters are well fulfilled.

[0065] Figure 6b shows the longitudinal spherical aberration and its chromatic variation at Lambda = 193,30 nm ± 0,015 nm for this embodiment 5, which as before mentioned is the remnant imaging error limiting the performance of this system.

[0066] It can be seen that with a moderately narrowed excimer laser source of Lambda = 193,3 nm with 15 pm band width a rectangular field of 26 x 9 mm can be imaged at a resolution of better than 0,2 µm.

[0067] A sixth embodiment is shown in Fig. 7 and table 6. Here, a deflecting prism DP is inserted for deflecting the light path towards the concave mirror 711.

[0068] Since the light rays inside the prism DP spread apart less than when they are in air (or nitrogen or helium), the field size can be increased by a certain amount without introducing any vignetting of the light rays by the prism edges. The importance of this design modification increases at higher numerical Aperture. Vignetting of rays limits how large a field size can be handled by the folding elements, and even a relatively small increase in field size is very desirable - for a variety of reasons, including the possibility of shrinking all lens diameters for a given field required. It turns out not to be relevant to try this for the second flat mirror DM2. While Fig. 7 schematically shows the deflecting mirror region, exemplary lens data for a full system are given in table 6. This Prism arrangement can also help to extend the free working distance or to use other mirror angles (e. g. 45°).

[0069] Embodiment 7, for which design data are given in table 7, shows the possible extension of the image with side numerical aperture well beyond the 0,7 value of the other examples. The value of NA = 0,8 is not yet limiting to this type of lens. The overall construction is as given in the other embodiments, thus no extra drawing is needed for explanation.

[0070] Embodiment 8 with lens data of table 8 gives a pure CaF_2 design for 157 nm wavelength as an example showing the possibilities of the inventive design for use with VUV wavelengths. The overall construction is very much like fig. 6a.

[0071] Other combinations of claimed features than explicitly described above are within the scope of the invention.

[0072] The possibilities of the Schupman achromat for achromatization with only one lens material are fully exploited in embodiments 1 and 8. In consequence, this embodiment 8 presents the first 157 nm design of the Schupman achromat suitable for VUV lithography. Insertion of aspheres and consequent reduction of number and thickness of lenses will further optimize this.

[0073] A new aspect of using a second material in a lens for avoiding compaction is given in embodiments 4 to 7.

[0074] To simplify achromatization by use of a second material very few elements made from this are sufficient as embodiments 3, 4, 6 and 7 show.

[0075] Preferably the lenses between the deflecting elements and the concave mirror are arranged in a compact unit with the latter as in embodiments 3 to 8. All lenses are more distant from the deflecting elements than from the concave mirror, their minimal distances do not exceed their maximum thicknesses (both taken over the diameter), or the length of the compact unit does not exceed its diameter, at least not by more than 50 %. The sophisticated design of the refractive lens system as presented allows for good correction at increased image side numerical apertures in the 0,65 to 0,85 range.

[0076] While examples are given for the scanning scheme of exposure, the invention as well is useful with step-and-repeat or stitching. Stitching allows for specifically smaller optics.

Table 1

Lambda = 193,3 nm   ß = 0,25   NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	40,000	
201	433,823	20,000	SIO2
202	Infinity	76,000	
DM1	Infinity	286,798	Angle 50,5°
203	371,257	25,000	SIO2
204	855,824	216,212	
205	-242,813	15,000	SIO2
206	-957,702	29,987	
207	-191,563	15,000	SIO2
208	-420,744	12,000	
209	267,741		Reflector
(203)		281,798	
DM2	Infinity	141,534	Angle 39,5°
210	341,605	45,000	SIO2
211	-302,390	0,266	
212	-314,725	15,000	SIO2
213	-535,921	21,847	
214	-293,712	15,000	SIO2
215	242,074	2,808	
216	253,649	50,000	SIO2
217	-418,716	1,000	
218	387,621	32,000	SIO2
219	Infinity	23,536	
220	338,439	20,000	SIO2
221	180,073	56,252	
222	-200,452	17,000	SIO2
223	-406,872	1,000	
224	830,485	35,000	SIO2
225	-406,246	137,396	
226	564,466	32,000	SIO2
227	-1292,800	1,000	
228	288,764	22,000	SIO2

229	169,297	57,016	
230	-189,642	28,572	SIO2
231	-398,135	81,777	
232	-476,268	32,000	SIO2
233	-238,618	1,000	
234	505,684	17,000	SIO2
235	259,770	13,056	
236	455,638	38,000	SIO2
237	-469,418	1,000	
238	236,178	15,000	SIO2
239=AP	145,030	2,543	
240	149,636	45,000	SIO2
241	1347,200	1,000	
242	138,086	29,000	SIO2
243	273,919	16,837	
244	-2450,800	36,643	SIO2
245	114,868	12,598	
246	183,269	33,000	SIO2
247	-427,093	0,100	
248	119,177	56,567	SIO2
249	352,582	0,100	
250	176,817	42,544	SIO2
251	-263,402	15,000	
IM	Infinity	0,000	

Table 2

Lambda = 193,3 nm   ß = -0,25   NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	40,000	
301	501,959	20,000	SIO2
302	6701,736	83,000	
DM1	Infinity		Angle 53,00°
303	-477,089		SIO2
304	-5445,982		
305	282,396		SI02
306	1204,642		
307	216,126		SIO2
308	519,194		
309	298,619		Reflector
(303)			
DM2	Infinity		Angle 37,00°
310	-277,399		SIO2
311	876,072		
312	384,127		SIO2
313	-245,187		
314	-297,630		SIO2
315	778,473		
316	-422,020		SIO2
317	945,111		
318	-336,194		SIO2
319	-169,717		
320	208,247		SIO2
321	414,789		
322	-639,842		SIO2
323	420,685		
324	-508,419		SIO2
325	1843,176		
326	-315,017		SIO2
327	-182,247		
328	197,495		SIO2

329	764,726	
330	572,623	SIO2
331	246,349	
332	-592,087	SIO2
333	-240,082	
334	-314,738	SIO2
335	745,437	
336	-219,102	SIO2
337	-178,632	
338	-269,565	SIO2
339=AP	-8665,509	
340	-165,739	SIO2
341	-378,291	
342	-5121,046	CAF2
343	457,764	
344	511,311	SIO2
345	-143,061	
346	-134,125	SIO2
347	-125,446	
348	-158,475	CAF2
349	451,948	
350	-122,592	SIO2
351	-830,354	
352	-374,272	SIO2
353	500,000	
IM	Infinity	

Table 3

Lambda = 193,3 nm   ß = -0,25   NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	40,000	
401	441,354	20,000	SIO2
402	-3082,575	82,000	
DM1	Infinity	404,580	Angle 51°
403	379,755	40,000	CAF2
404	-503,571	10,819	
405	-538,291	15,000	SIO2
406	-11216,000	23,000	
407	-289,982	15,000	SIO2
408	1481,373	35,434	
409	-212,610	15,000	SIO2
410	-422,622	10,747	
411	281,484	10,747	Reflector
(403)		391,580	
DM2	Infinity	95,000	Angle 39°
412	304,777	35,000	SIO2
413	-414,139	36,096	
414	-217,633	15,000	SIO2
415	291,419	15,871	
416	372,431	48,000	SIO2
417	-351,209	1,000	
418	478,050	34,000	SIO2
419	-840,313	52,353	
420	336,231	20,000	SIO2
421	175,364	55,562	
422	-230,487	17,000	SIO2
423	-430,797	1,000	
424	648,294	40,000	SIO2
425	-404,757	99,810	
426	527,066	30,000	SIO2
427	-13296,000	1,000	
428	288,592	22,000	SIO2

429	167,355	54,577	
430	-201,179	20,000	SIO2
431	-801,011	103,872	
432	-585,801	36,000	SIO2
433	-252,132	1,000	
434	457,102	17,000	SIO2
435	260,610	9,580	
436	343,579	43,000	SIO2
437	-739,447	1,000	
438	226,319	18,500	SIO2
439	173,228	16,103	
440	272,220	34,000	SIO2
441=AP	-7972,902	1,000	
442	165,067	34,000	SIO2
443	374,040	12,889	
444	2219,918	22,000	CAF2
445	-490,695	0,100	
446	-715,705	12,000	SIO2
447	134,285	0,100	
448	123,907	36,879	SIO2
449	111,965	9,498	
450	147,332	35,000	CAF2
451	-967,651	0,100	
452	115,241	69,555	SIO2
453	921,256	0,100	
454	294,383	28,447	SIO2
455	-500,000	15,000	
IM	Infinity		

Table 4

Lambda = 193,3 nm   ß = -0,25   NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	35,000	
501	407,048	16,000	SIO2
502	-85814,000	82,000	
DM1	Infinity	431,676	Angle 50°
503	524,134	35,000	SIO2
504	-657,304	8,785	
505	-587,479	15,000	SIO2
506	1940,811	25,643	
507	-324,153	15,000	SIO2
508	-23676,000	37,709	
509	-201,728	15,000	SIO2
510	-422,094	12,854	
511	282,375		Reflector
(503)		422,676	
DM2	Infinity	110,772	Angle 40°
512	373,692	35,000	SIO2
513	-410,297	50,772	
514	-222,817	15,000	SIO2
515	317,101	6,370	
516	349,335	48,000	SIO2
517	-362,479	1,000	
518	729,698	34,000	SIO2
519	-931,019	57,653	
520	371,363	20,000	SIO2
521	210,389	53,764	
522	-248,647	17,000	SIO2
523	-428,501	1,000	
524	937,198	40,000	SIO2
525	-388,007	113,824	
526	567,461	30,000	SIO2
527	-4351,070	1,000	
528	282,352	22,000	SIO2

529	185,586	56,362	
530	-234,431	20,000	SIO2
531	-557,904	132,665	
532	-408,165	35,442	SIO2
533	-266,966	1,000	
534	404,076	17,000	SIO2
535	238,987	14,763	
536	379,049	43,000	SIO2
537	-737,556	1,000	
538	245,637	18,500	SIO2
539	178,878	12,206	
540	245,508	34,000	SIO2
541	2061,364	10,000	
AP	Infinity	0,000	
542	168,071	34,000	SIO2
543	473,781	9,798	
544	1851,461	22,000	CAF2
545	-494,253	0,100	
546	-719,297	12,000	SIO2
547	132,814	0,100	
548	127,155	34,780	SIO2
549	118,260	11,187	
550	169,575	35,000	SIO2
551	-844,545	0,100	
552	111,623	74,968	CAF2
553	1756,460	0,100	
554	239,829	26,117	CAF2
555	-500,000	15,000	
IM	Infinity	0,000	

Table 5

Lambda = 193,3 nm   ß = -0,25   NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	35,000	
601	443,397	16,000	SIO2
602	-3263,101	82,000	
DM1	Infinity	431,967	Angle 50°
603	510,641	35,000	SIO2
604	-953,685	12,327	
605	-534,546	15,000	SIO2
606	1546,359	27,623	
607	-295,422	15,000	SIO2
608	-1911,545	32,819	
609	-212,072	15,000	SIO2
610	-404,269	12,229	
611	279,883		Reflector
(603)		422,967	
DM2	Infinity	109,448	Angle 40°
612	338,847	28,000	SIO2
613	-769,850	31,900	
614	1373,814	18,000	SIO2
615	-915,108	37,909	
616	-239,573	15,000	SIO2
617	279,202	6,538	
618	301,416	46,477	SIO2
619	-437,969	1,000	
620	722,212	30,074	SIO2
621	-1063,807	23,211	
622	381,419	19,000	SIO2
623	193,859	52,872	
624	-235,061	17,000	SIO2
625	-412,453	1,000	
626	990,052	40,000	SIO2
627	-337,530	95,112	
628	529,636	30,000	SIO2

629	-0,208	1,000	
630	264,737	20,000	SIO2
631	173,477	55,898	
632	-213,164	19,000	SIO2
633	-478,343	127,971	
634	-384,253	29,998	SIO2
635	-241,972	1,000	
636	381,178	17,000	SIO2
637	218,858	11,314	
638	296,282	43,000	SIO2
639	-966,118	1,000	
640	230,570	18,500	SIO2
641	172,880	14,657	
642	271,493	30,000	SIO2
643	-49526,000	4,000	
AP	Infinity	0,000	
644	156,048	36,000	SIO2
645	474,860	12,986	
646	-4892,676	20,000	SIO2
647	-452,665	0,100	
648	-711,904	34,541	SIO2
649	122,051	9,933	
650	171,475	33,021	SIO2
651	-967,318	0,100	
652	112,494	72,297	CAF2
653	3642,643	0,100	
654	250,427	26,033	CAF2
655	-500,000	15,000	
IM	Infinity	0,000	

Table 6

Lambda = 193,3 nm ß = -0,25 NA = 0,7

No.	Radius	Thickness	Glass
0	Infinity	35,000	
701	396,818	16,000	SIO2
702	-411120,000	1,000	
DP	Infinity	85,500	SIO2
DP	Infinity	435,933	Angle 50°
703	559,897	35,000	SIO2
704	-763,942	2,707	
705	-627,112	15,000	SIO2
706	2056,900	24,065	
707	-323,749	15,000	SIO2
708	-4114,500	41,268	
709	-197,452	15,000	SIO2
710	-416,693	13,024	
711	278,696		Reflector
(703)		420,933	
DM2	Infinity	84,857	Angle 40°
712	391,689	35,000	SIO2
713	-391,139	54,674	
714	-217,120	15,000	SIO2
715	328,292	6,584	
716	363,974	48,000	SIO2
717	-352,092	11,973	
718	753,003	34,000	SIO2
719	-915,634	62,045	
720	369,054	20,000	SIO2
721	218,165	56,274	
722	-247,872	17,000	SIO2
723	-420,231	1,000	
724	970,166	40,000	SIO2
725	-383,655	110,429	
726	556,298	30,000	SIO2
727	-5145,200	1,000	

728	275,093	22,000	SIO2
729	186,724	57,861	
730	-249,939	24,499	SIO2
731	-573,695	138,278	
732	-424,514	35,114	SIO2
733	-274,834	1,000	
734	391,263	17,000	SIO2
735	226,128	16,728	
736	383,272	43,000	SIO2
737	-863,203	1,000	
738	239,284	18,500	SIO2
739	178,197	11,299	
740	237,727	34,000	SIO2
741	1618,000	10,000	
AP	Infinity	0,000	
742	165,688	34,000	SIO2
743	445,266	9,217	
744	1247,900	22,000	CAF2
745	-503,423	0,000	
746	-771,731	12,000	SIO2
747	131,678	0,100	
748	124,872	29,133	SIO2
749	115,885	13,283	
750	179,986	35,000	SIO2
751	-802,711	0,100	
752	110,497	77,422	CAF2
753	2393,500	0,100	
754	234,953	25,804	CAF2
755	-500,000	15,000	
IM	Infinity	0,000	

Table 7

Lambda = 193 nm ß=-0,25 NA = 0,8

No.	Radius	Thickness	Glass
0	Infinity	35,000	
801	355,625	15,000	SIO2
802	Infinity	84,000	
DM1	Infinity	393.919	Angle 50°
803	621,321	30,000	SIO2
804	17349,000	15,577	
805	-522,771	15,000	SIO2
806	7450,061	28,795	
807	-279,969	15,000	SIO2
808	-692,552	26,633	
809	-231,205	15,000	SIO2
810	-419,760	13,994	
811	283,256		Reflector
(803)		384,919	
DM2	Infinity	103,131	Angle 40°
812	363,520	35,000	SIO2
813	-312,546	19,745	
814	-203,460	15,000	SIO2
815	417,901	4,913	
816	637,371	44,999	SIO2
817	-299,660	1,000	
818	670,513	36,000	SIO2
819	-607,949	99,443	
820	409,543	20,000	SIO2
821	184,175	56,726	
822	-190,739	18,000	SIO2
823	-300,666	1,000	
824	2541,548	35,000	SIO2
825	-423,211	82,343	
826	529,976	40,000	SIO2
827	-575,433	1,000	
828	338,904	22,000	SIO2

829	161,992	77,036	
830	-180,232	20,000	SIO2
831	-286,886	60,230	
832	1358,390	50,000	SIO2
833	-310,335	1,000	
834	299,546	17,000	SIO2
835	185,330	22,475	
836	318,393	15,000	SIO2
837	240,343	11,470	
838	351,936	35,000	SIO2
839	-1892,972	1,000	
840	241,744	18,500	SIO2
841	201,167	6,992	
842	233,761	35,000	SIO2
843	1187,547	0,000	
AP	Infinity	6,993	
844	173,633	65,000	CAF2
845	-647,630	0,100	
846	-1026,314	15,000	SIO2
847	134,041	12,672	
848	177,508	43,000	SIO2
849	-552,796	0,100	
850	111,087	82,051	CAF2
851	366,445	0,100	
852	201,556	9,977	CAF2
853	Infinity	15,000	
IM	Infinity		

Table 8

Lambda 157,000 nm ± 2 pm NA = 0,7 ß = -0,25

No.	Radius	Thickness	Glass
0	Infinity	35,000	
901	509,596	16,000	CAF2
902	-1709,182	82,000	
DM1	Infinity	430,770	Angle 50°
903	559,504	35,000	CAF2
904	-1229,460	18,117	
905	-727,847	15,000	CAF2
906	1261,260	27,332	
907	-297,498	15,000	CAF2
908	-1565,150	32,707	
909	-205,835	15,000	CAF2
910	-396,253	12,181	
911	279,103	Reflector	ϕ 252 mm
(903)		420,578	
DM2	Infinity	73,026	Angle 40°
IMI	Infinity	34,034	
912	341,070	28,000	CAF2
913	-1505,473	32,408	
914	969,048	18,000	CAF2
915	-805,764	37,523	
916	-248,947	15,000	CAF2
917	286,272	5,893	
918	307,931	45,973	CAF2
919	-386,903	1,000	
920	1003,377	28,290	CAF2
921	-945,839	20,042	
922	397,781	19,000	CAF2
923	197,943	53,200	
924	-231,060	17,000	CAF2
925	-406,748	1,000	
926	878,953	40,000	CAF2
927	-351,000	100,639	

928	481,080	30,000	CAF2
929	11551,730	1,000	
930	282,768	20,000	CAF2
931	179,880	51,341	
932	-217,737	19,000	CAF2
933	-511,417	127,776	
934	-377,857	29,786	φ240 mm CAF2
935	-241,099	1,000	
936	377,020	17,000	CAF2
937	218,220	11,262	
938	299,020	43,000	CAF2
939	-943,927	1,000	
940	228,020	18,500	CAF2
941	168,921	13,866	
942	263,149	30,000	CAF2
943	-27570,214	0,752	
AP	Infinity	8,754	
944	157,192	36,000	CAF2
945	476,977	13,281	
946	-5291,918	20,000	CAF2
947	-428,700	0,100	
948	-634,165	34,624	CAF2
949	123,520	10,454	
950	180,781	33,303	CAF2
951	-732,821	0,100	
952	115,913	72,125	CAF2
953	3615,409	0,100	
954	308,142	25,802	CAF2
955	-500,000	15,000	
IM	Infinity		

Refractive Indices CaF_2

Lambda = 157,002	157,000	156,998
n = 1,560047	1,560052	1,560057

Claims

1. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, with lenses made of a first material and lenses made of a second material, characterized in that no more than four, preferable no more than three lenses are made of said second material.

2. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, where the catadioptric system has at least a deflecting element, a concave mirror and a number of lenses between them, characterized in that the concave mirror and all lenses arranged between the deflecting element and the concave mirror are arranged in a compact unit, where preferably the distance from any of said lenses to a deflecting element is greater than its distance to the concave mirror.

3. Projection exposure lens with an object side catadioptric system, where the catadioptric system has at least a deflecting element, a concave mirror and a number of lenses, characterized in that the catadioptric system has at least one positive lens between the object side and the first deflecting element, not more than one positive and not more than three negative lenses between the first deflecting element and the concave mirror.

4. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, characterized in that the refractive lens system from the intermediate image side on has

   — a first lens group of positive refractive power
   — a second lens group of negative refractive power
   — a third lens group of positive refractive power
   — a fourth lens group of negative refractive power
   — a fifth lens group of positive refractive power.

5. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, characterized in that at least one -+power doublet with a negative power lens and a positive power lens in this sequence from the object side is arranged in said refractive lens system.

6. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, characterized in that said refractive lens system is composed of a field lens group, an intermediate correcting lens group and a focussing lens group.

7. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, characterized in that said catadioptric system has an imaging ratio greater than 0,95, but different from unity.

8. Projection exposure lens with an object side catadioptric system, an intermediate image and a refractive lens system, characterized by the combination of features of at least two of claims 1 to 7.

9. Projection exposure lens according to at least one of claims 1 to 8, characterized in that the refractive lens system contains at least a pair of menisci, the convex surface of the intermediate-image-side meniscus facing to the intermediate image, the convex surface of the other facing oppositely.

10. Projection exposure lens according to claims 6 and 9, characterized in that said at least one pair of menisci is arranged in said correcting lens group.

11. Projection exposure lens according to claims 5 and 6, characterized in that said -+power doublet is arranged in said focussing lens group.

12. Projection exposure lens according to at least one of claims 5 to 11, characterized in that one of said -+power doublets is arranged next to the system aperture.

13. Projection exposure lens according to at least one of claims 1 to 12, characterized in that at most one lens of said catadioptric system is made of a second lens material.

14. Projection exposure lens according to at least one of claims 1 to 13, characterized in that the diameter of lenses made of said second lens material does not exceed the 0,85 fold of the diameter of the biggest optical element.

15. Projection exposure lens according to at least one of claims 1 to 14, characterized in that the diameter of lenses made of said second lens material does not exceed 220 mm.

16. Projection exposure lens according to at least one of claims 1 to 15, characterized in that the catadioptric system contains no more than six, preferably no more than five lenses.

17. Projection exposure lens according to at least one of claims 1 to 16, characterized in that the longitudinal chromatic aberration is less than 0,015 µm per a band width of 1 pm at 193 nm.

18. Projection exposure lens according to at least one of claims 1 to 16, characterized in that the longitudinal chromatic aberration is less than 0,05 µm per a band width of 1 pm at 157 nm.

19. Projection exposure lens according to at least one of claims 1 to 18, characterized in that the imaging ratio of the catadioptric system is greater than 0,8, preferably greater than 0,95.

20. Projection exposure lens according to at least one of claims 1 to 19, characterized in that in the refractive lens system all lenses made of said second lens material are arranged in a converging light beam next to the image plane.

21. Projection exposure lens according to at least one of claims 1 to 20, characterized in that it is both side telecentric.

22. Projection exposure lens according to claim 5, characterized in that it has at least one beam waist in the refracting subsystem and said -+power doublets are arranged behind the last beam waist.

23. Projection exposure lens according to claim 5 or 22, characterized in that said -+ doublets are arranged such that the light beam diameter inside their lens elements is more than 80 % of the maximum beam diameter.

24. Projection exposure lens according to at least one of the claims 1 to 23, characterized in that a reflecting prism is inserted for reflection of the light beam between the object and the concave mirror.

25. Projection exposure lens according to at least one of claims 1 to 24, characterized in that it is designed for use with 248 nm or 193 nm light and said first lens material is fused silica and said second lens material is calcium fluoride.

26. Projection exposure lens according to at least one of claims 1 to 24, characterized in that the first lens material is calcium fluoride.

27. Projection exposure lens according to at least one of claims 1 to 26, characterized in that exactly one lens is placed between the object and the first deflecting element.

28. Projection exposure lens according to claim 27, characterized in that the ratio of focal length of said lens before said first deflecting mirror over the distance from said lens to said concave mirror is unity within (+/-) fifteen percent.

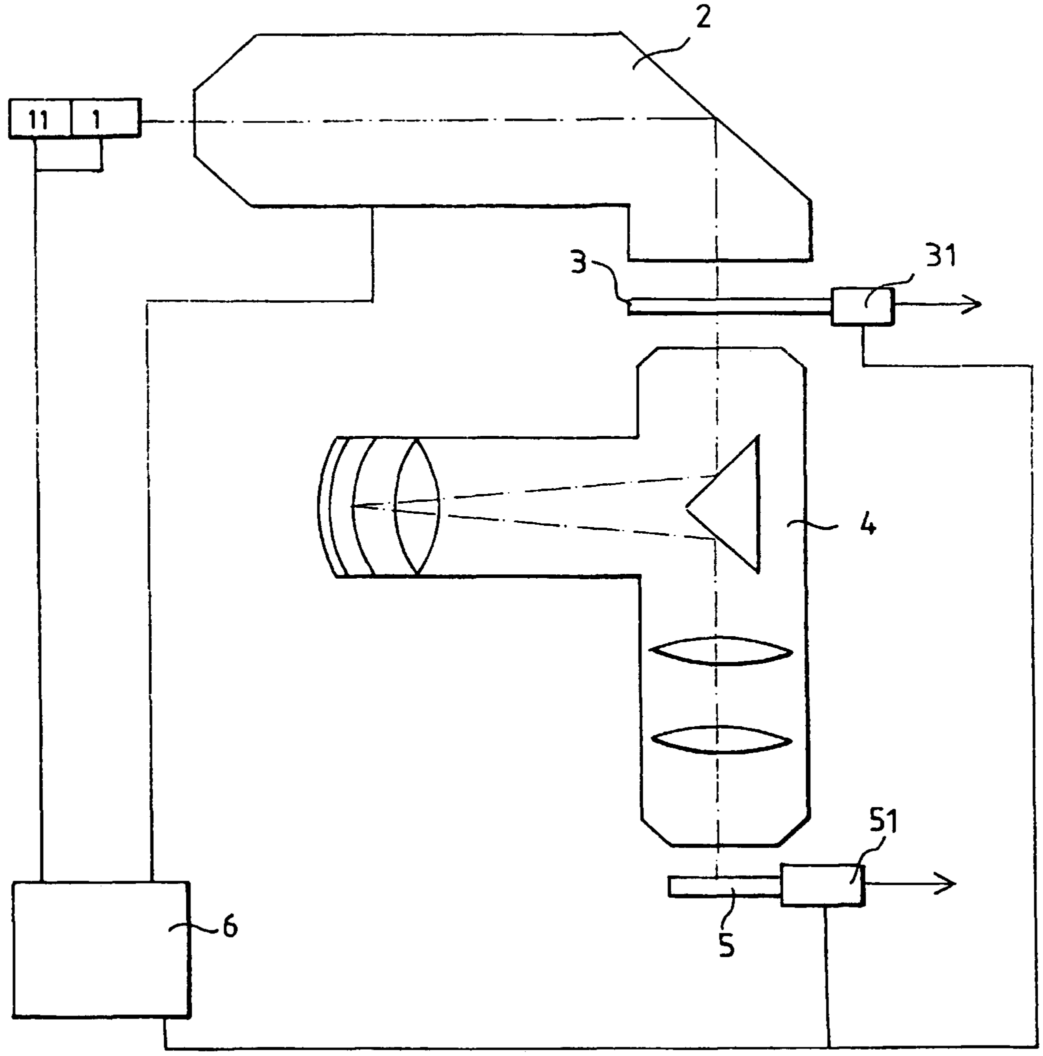
29. Projection exposure apparatus comprising

— an excimer laser light source
— an illuminating system
— a mask handling and positioning system
— a projection exposure lens according to at least one of claims 1 to 28
— a wafer handling and positioning system.

30. A method of producing microstructured devices by lithography making use of a projection exposure apparatus according to claim 29.

31. A method according to claim 30, characterized in that use is made of step- and repeat, scanning or stitching exposure schemes.

FIG. 1



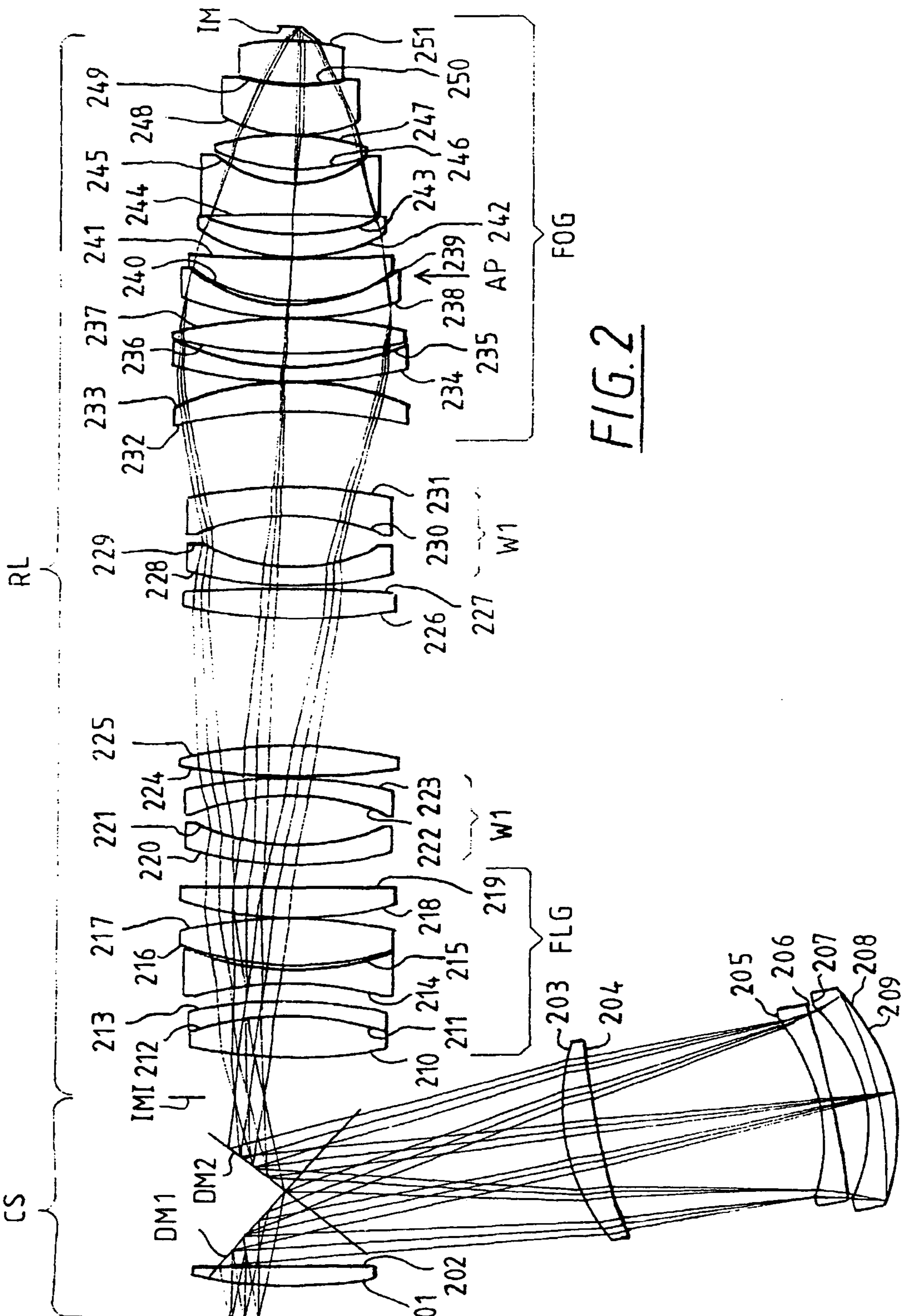

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FIG. 2

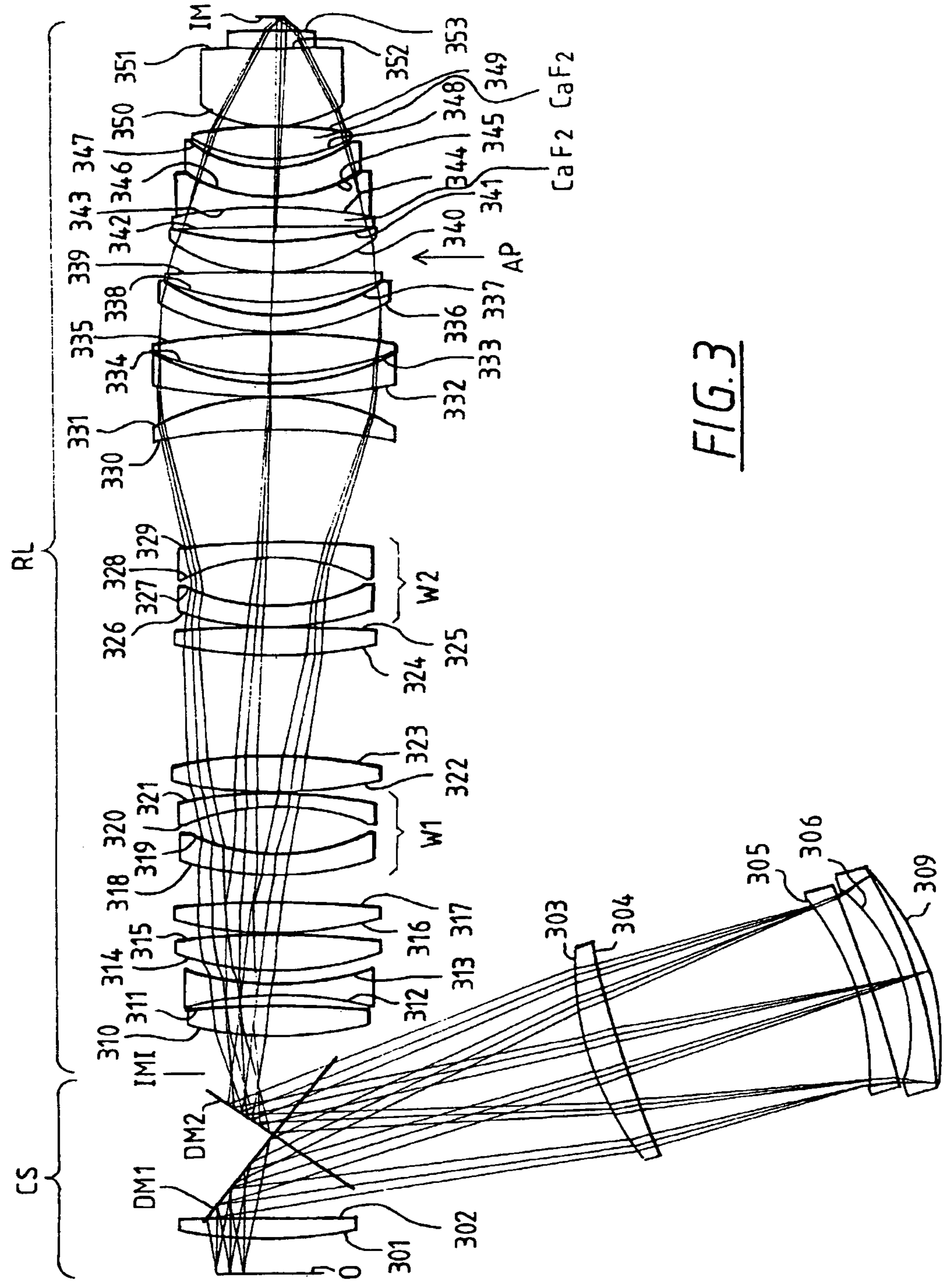
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FIG.3

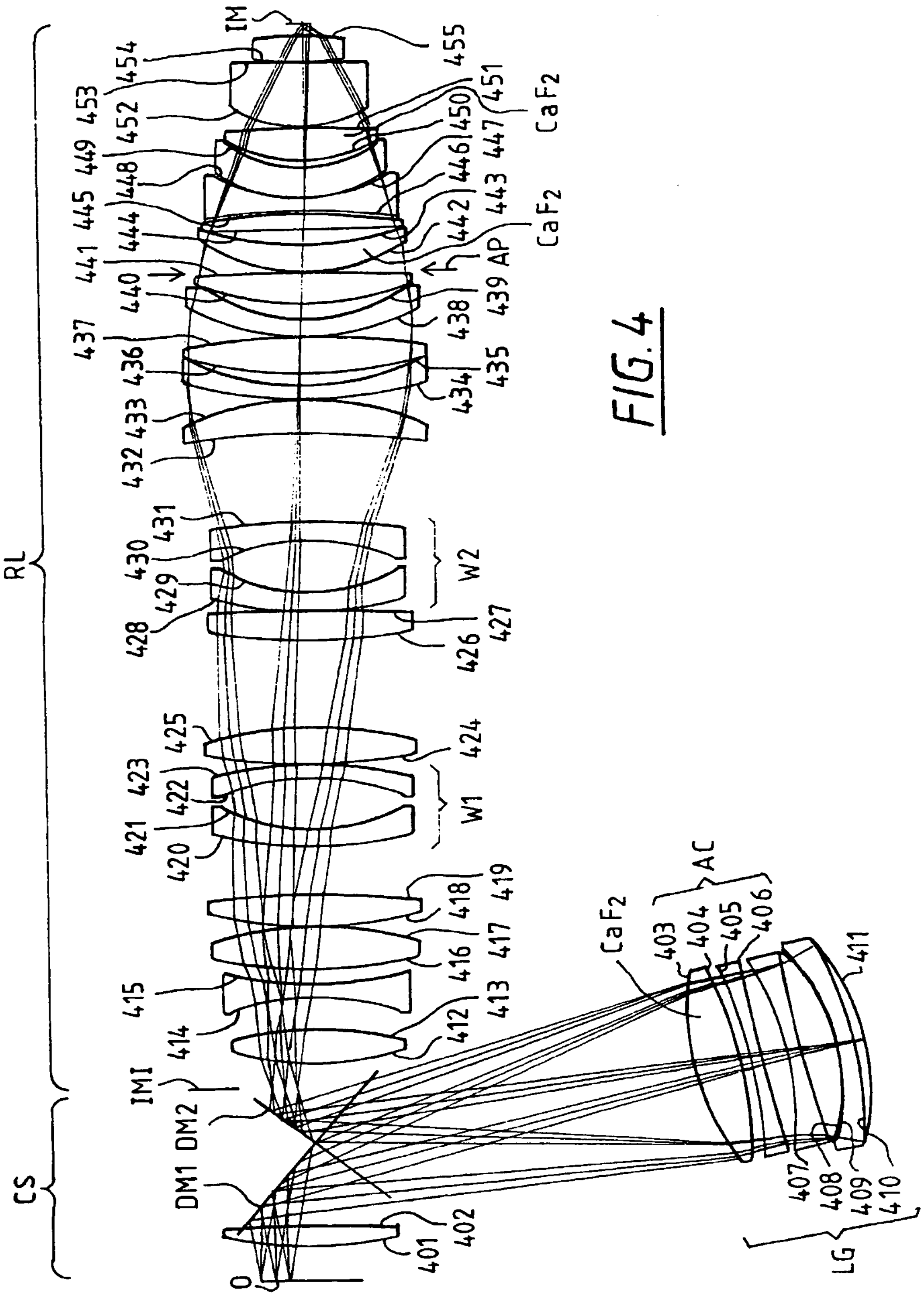
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FIG. 4

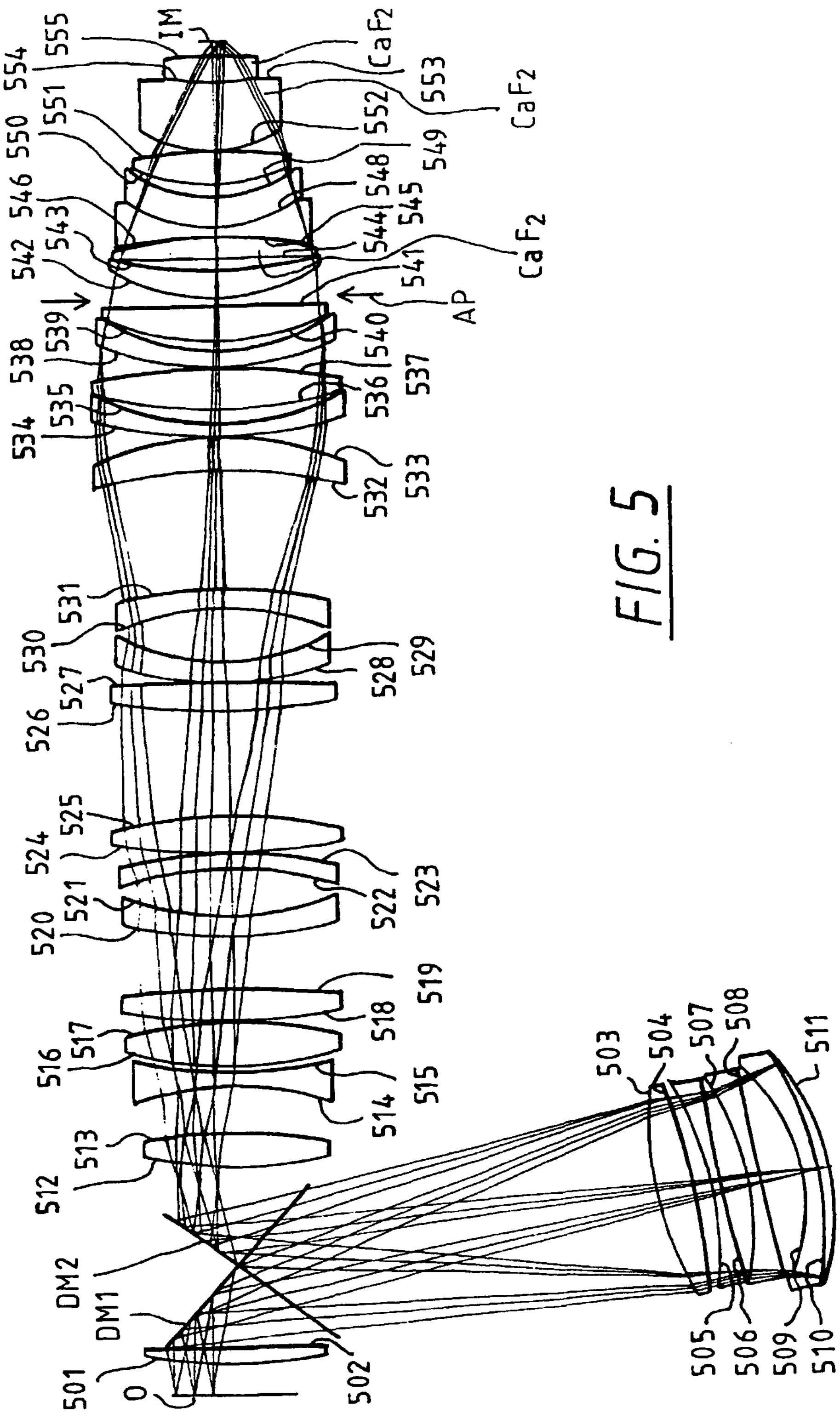
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FIG. 5

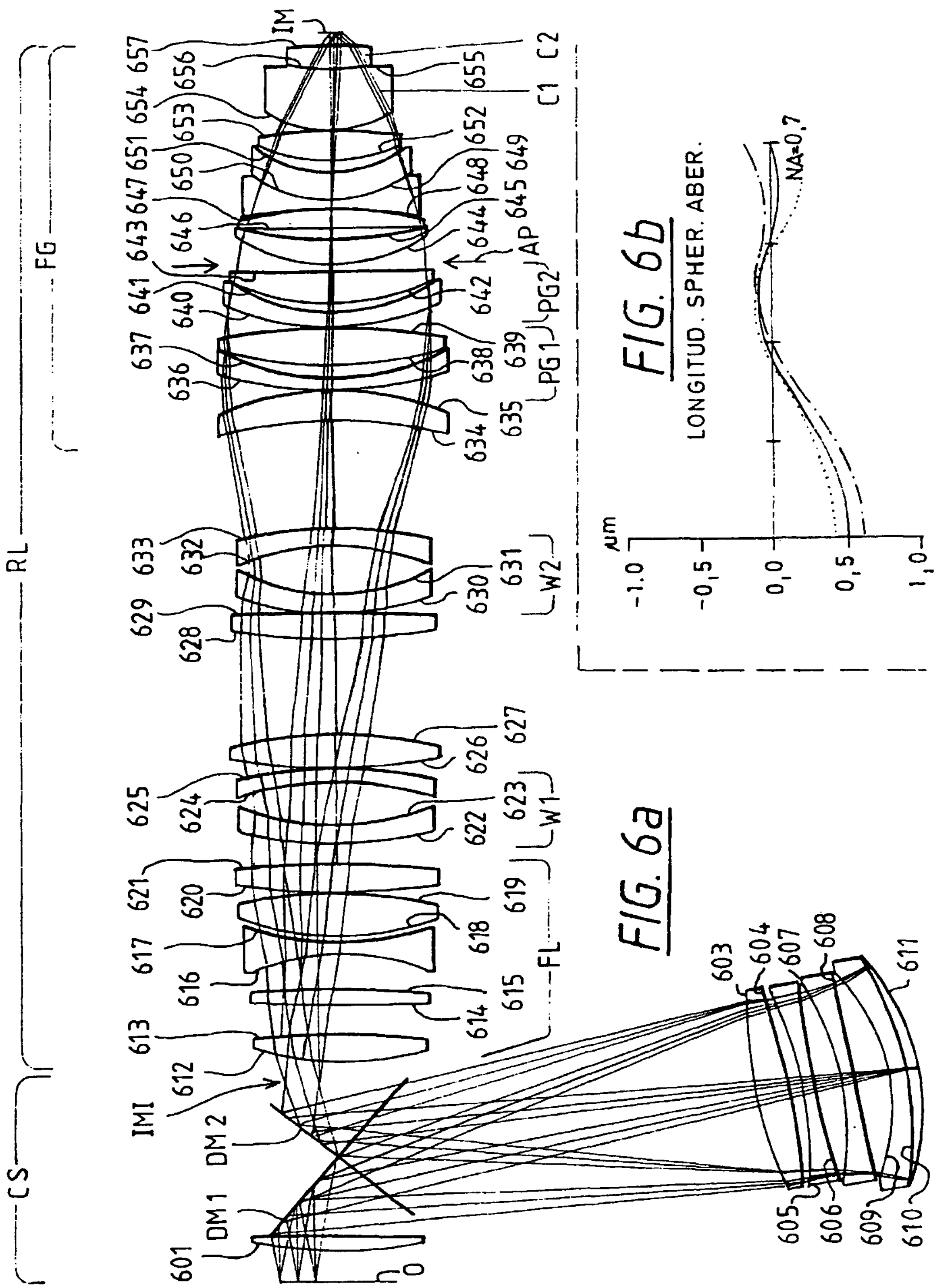
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FIG. 6a

FIG. 6b

FIG. 7